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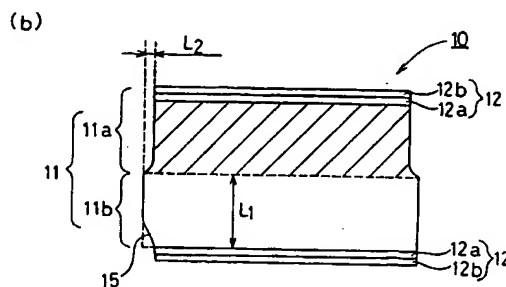
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(54) Diamond heat sink and method of manufacturing the same.

(57) A polycrystalline diamond is prepared by chemical vapor deposition (step 101). A surface of the polycrystalline substance are metallized (step 102). The metallized surface of the polycrystalline diamond is grooved with a YAG laser (step 103). A wedge or the like is driven into the grooves of the polycrystalline diamond to pressurize the same, whereby the polycrystalline diamond is divided along the grooves (step 104). Alternatively, a surface of a polycrystalline diamond prepared by chemical vapor deposition may be grooved with a YAG laser (step 112), so that the surface of the polycrystalline diamond is thereafter metallized (step 113). A diamond heat sink (10) includes a first layer (11a) grooved with a laser and a mechanically divided second layer (11b). Graphite adheres to the surface of the first layer (11a). The second layer (11b) is greater in surface roughness than the first layer (11a).

FIG.1



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BACKGROUND OF THE INVENTION

Field of the Invention

5 The present invention relates to a diamond heat sink and a method of manufacturing the same, and more particularly, it relates to a diamond heat sink containing diamond which is prepared by chemical vapor deposition and a method of manufacturing the same.

Description of the Background Art

10 A heat sink (radiator) is adapted to efficiently dissipate heat which is generated in operation of a device such as a semiconductor laser diode, an LED (light emitting diode), a semiconductor high frequency device or the like. The material for such a heat sink is selected in accordance with the heating value of the device to which the same is applied. Table 1 shows physical properties of various heat sink materials.

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Table 1

| Physical Properties | Monocrystalline Diamond | Vapor-Deposited Diamond | cBN Sintered Body | Cu | Sic | Cu-W | BdO | AlN | Si |
|---|-------------------------|-------------------------|-------------------|------------------------|------------------|------------------------|------------------|------------------|-----------------------|
| Density (g/cm ³) | 3.52 | 3.52 | 3.49 | 8.9 | 3.1 | 16.4 | 2.9 | 3.26 | 2.3 |
| Vickers Hardness (kg/mm ²) | 12,000 | 12,000 | 6,000 | 80 | - | 260 | 1,200 | 1,200 | - |
| Transverse Rapture Strength (kg/mm ²) | 400 | 200 | - | - | 40 | 136 | 20 | 30 | - |
| Thermal Conductivity (W/m·K) | 2,000 | 1,000 | 600 | 390 | 270 | 250 | 250 | 270 | 140 |
| Thermal Expansion Coefficient (x10 ⁻⁶ /°C) | 2.3 | - | 3.7 | 16.5 | 3.7 | 8.5 | 7.6 | 4.5 | 4.2 |
| Specific Heat (cal/g·°C) | 0.122 | - | - | 0.092 | - | 0.044 | 0.25 | 0.16 | 0.18 |
| Electric Resistivity (Ω·cm) | 10 ¹⁶ | 5 × 10 ⁹ | 10 ¹¹ | 1.7 × 10 ⁻⁶ | 10 ¹³ | 3.4 × 10 ⁻⁶ | 10 ¹⁵ | 10 ¹³ | 2.3 × 10 ⁵ |
| Dielectric Constant (1MHz) | 5.7 | 6.5 | 6.5 | - | 40 | - | 6.7 | 8.9 | - |

As shown in Table 1, diamond has high thermal conductivity. Therefore, a diamond heat sink is employed as a heat dissipating parts for a device having a high heating value such as a high power semiconductor laser for communication, optical memory, solid state laser pumping or the like, for example. In the present circumstances, such a diamond heat sink is mainly prepared from natural or synthetic monocrystalline diamond.

Fig. 7 is a process diagram successively showing steps in conventional methods of manufacturing diamond heat sinks. Referring to Fig. 7, a monocrystalline diamond material is prepared by high pressure synthesis or the like (step 601). According to a first manufacturing method, this monocrystalline diamond material is cut into chips with a diamond saw (step 610). The cut diamond chips are arranged side by side with no clearances and metallized (step 611), so that only upper and bottom surfaces of each diamond chip are metallized. Thus, a diamond heat sink is completed by the first manufacturing method.

According to a second manufacturing method, on the other hand, a monocrystalline diamond material is cut into chips with a diamond saw (step 610), similarly to the first manufacturing method. Each of the as-cut diamond chips is metallized on all faces (step 612). Side surfaces of the entirely metallized diamond chip are ground with a diamond grindstone (step 613), so that metallized films are left only on upper and bottom surfaces of the diamond chip. Thus, a diamond heat sink is completed by the second manufacturing method.

According to a third manufacturing method, a monocrystalline diamond material is metallized before cutting (step 620). The metallized monocrystalline diamond material is cut with a diamond saw into chips, each of which is then cut into a final shape (step 621). Thus, a diamond heat sink is completed by the third manufacturing method.

Conventional diamond heat sinks are manufactured in the above manners.

In each of the aforementioned conventional methods of manufacturing diamond heat sinks, a monocrystalline diamond material is cut with a diamond saw. Therefore, the diamond material cannot be cut in high accuracy, and the cutting speed is very slow. Further, a great deal of margins result from the cutting and grinding steps, leading to an inferior yield. Thus, a diamond heat sink cannot be easily manufactured by a conventional method, leading to inferiority in mass productivity.

On the other hand, each of Japanese Patent Laying-Open Nos. 2-268917 (1990) and 3-138106 (1991) discloses a method of working a monocrystalline diamond material using no diamond saw.

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SUMMARY OF THE INVENTION

An object of the present invention is to provide a method of manufacturing a diamond heat sink, which can easily work a diamond material with an excellent yield and high mass productivity.

30 Another object of the present invention is to provide a diamond heat sink which is insulated between the upper and the bottom faces.

In order to attain the aforementioned first object, the inventive method is adapted to manufacture a diamond heat sink containing diamond which is synthesized by chemical vapor deposition and having a pair of opposing main surfaces which are electrically insulated from each other. This method includes a step of preparing a polycrystalline diamond, a step of forming grooves in surfaces of the polycrystalline diamond, and a step of mechanically dividing the polycrystalline diamond along the grooves.

According to the inventive method of manufacturing a diamond heat sink, it is possible to simultaneously divide the polycrystalline diamond along the grooves. Thus, the diamond material can be easily worked in a shorter time. Further, cut margins result only from the grooves, whereby the yield is improved. 40 Thus, the working cost is reduced by reduction of the working time and improvement of the yield.

Preferably, the step of forming grooves is carried out with a YAG (yttrium aluminum garnet) laser. Due to such employment of the laser, it is possible to accurately and efficiently work the diamond material.

In order to attain the aforementioned second object, the diamond heat sink according to the present invention contains polycrystalline diamond which is synthesized by vapor deposition and has a pair of opposing main surfaces which are electrically insulated from each other. The diamond heat sink includes first and second layers between the pair of main surfaces. Graphite adheres to the outer peripheral surface of the first layer, while the outer peripheral surface of the second layer is greater in surface roughness than that of the first layer.

If the diamond heat sink includes only the first layer, graphite will remain, so that insulation can not be obtained between the two main surfaces. The diamond heat sink according to the present invention obtained by forming a groove to divide the polycrystalline diamond along the groove inevitably has a second layer to which graphite does not adhere and then, the insulation between the two main surfaces can be maintained.

Preferably, a defect, such as chipping, in an edge of the second layer is not more than 50 μm in size.

55 In general, such an edge is used as the basis of location for soldering a laser diode chip or the like. When a large defect exceeding 50 μm is caused in this edge, therefore, it is difficult to locate the laser diode chip or the like. Further, such a large defect leads to reduction in heat dissipating property.

Preferably, electric resistance along the direction of thickness of the second layer is at least $10 \times 10^6 \Omega$.

In general, a semiconductor laser requires electric resistance of $1 \times 10^6 \Omega$, and characteristics of the semiconductor laser are deteriorated when the resistance is less than the said value.

Preferably, electric resistance across the pair of main surfaces of the diamond heat sink is $1 \times 10^6 \Omega$.

Preferably, the second layer has a thickness of at least 0.03 mm and not more than 0.3 mm. In order to attain electric resistance of at least $1 \times 10^6 \Omega$ along the direction of thickness of the second layer, it is necessary to make its thickness at least 0.03 mm. As the thickness of the second layer is increased, however, a defect in the edge is easily caused in the second layer when the diamond is divided and also such a defective portion is increased in size. In order to suppress the defective portion which is caused in an edge of the second layer to not more than 50 μm in size, therefore, it is necessary to make the thickness of the second layer not more than 0.3 mm.

Preferably, the polycrystalline diamond has electric resistivity of $10^9 \Omega \cdot \text{cm}$. Such electric resistivity of at least $10^9 \Omega \cdot \text{cm}$ is at least necessary for attaining electric resistance of at least $1 \times 10^6 \Omega$ along the direction of thickness of the second layer.

Preferably, the polycrystalline diamond has thermal conductivity of at least $5 \text{ W/cm} \cdot \text{K}$ and not more than $20 \text{ W/cm} \cdot \text{K}$ at room temperature. Due to restriction of an usual apparatus and the method for preparing polycrystalline diamond, the upper limit of the thermal conductivity of diamond is $20 \text{ W/cm} \cdot \text{K}$. In order to apply diamond which exhibits high performance to a heat sink, the lower limit of its thermal conductivity is preferably at least $5 \text{ W/cm} \cdot \text{K}$.

The polycrystalline diamond which is synthesized by chemical vapor deposition preferably has thermal conductivity of at least $5 \text{ W/cm} \cdot \text{K}$ in a temperature range from the room temperature to 200°C . Further, the grain diameter of the polycrystalline diamond is preferably not more than 50 μm , so that substantially less defect is caused when the polycrystalline diamond is divided.

Preferably, the diamond heat sink includes a metallized film, which is formed at least on all or a portion of either one of the pair of main surfaces. This metallized film is required for soldering a laser diode chip, as well as for soldering the heat sink itself to a stem.

Preferably, the metallized film includes a first film which is formed on at least one of the pair of main surfaces and a second film which is formed on the surface of the first film.

Preferably, the first film included in the metallized film is made of at least one element selected from a group of Ti, Cr, W and Ni, while the second film is made of at least one element selected from a group of Pt, Pd, Ni, Mo, Au, Ag, Cu, Sn, In, Ge and Pb.

The first film is adapted to react with the diamond and improve adhesion. A metal material for serving such a function of the first film is prepared from at least one element selected from a group of Ti, Cr, W and Ni. On the other hand, the second film is adapted to contribute to heat resistance and solderability. A metal material for serving such a function of the second film is prepared from at least one element selected from a group of Pt, Pd, Ni, Mo, Au, Ag, Cu, Sn, In, Ge and Pb.

The as-completed heat sink has standard dimensions of at least 0.1 mm and not more than 1 mm in thickness and at least 0.2 mm and not more than 50 mm in length and width.

While a polycrystalline diamond is employed in the inventive diamond heat sink and the method of manufacturing the same, the following problems are caused if a monocrystalline diamond is employed. A polycrystalline diamond has transverse rapture strength of 200 kg/mm^2 , while a monocrystalline diamond has higher transverse rapture strength of 400 kg/mm^2 . Thus, the monocrystalline diamond is employed, therefore, it is difficult to divide the same. On the other hand, a polycrystalline diamond is broken mainly along grain boundaries, while a monocrystalline diamond is cleaved along the (111) plane. Therefore, the monocrystalline diamond is easier to crack, and leading to a large defect. Thus, the yield is reduced. Further, a polycrystalline diamond attains a material having a large area, while a monocrystalline diamond attains a material of about 5 mm by 5 mm at the most. Thus, the monocrystalline diamond is inferior in productivity.

As hereinabove described, a monocrystalline diamond has various problems. Therefore, a polycrystalline diamond is employed in the inventive diamond heat sink and the method of manufacturing the same.

The foregoing and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

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Fig. 1(a) is a process diagram schematically showing a method of manufacturing a diamond heat sink according to the present invention;

- Fig. 1(b) is a side elevational view schematically showing the structure of the diamond heat sink which is manufactured according to the inventive method;
- Figs. 2(a) to 2(c) are perspective views showing the method of manufacturing a diamond heat sink according to the present invention along steps;
- 5 Fig. 3 illustrates the structure of a diamond heat sink according to the present invention;
- Fig. 4 is a graph showing relations between laser beam machining conditions for a polycrystalline diamond which is synthesized by hot filament CVD and depths of worked grooves;
- Fig. 5 is a side elevational view schematically showing the structure of a diamond heat sink according to Example of the present invention;
- 10 Fig. 6 is a side elevational view schematically showing the structure of a diamond heat sink according to another Example of the present invention; and
- Fig. 7 is a process diagram schematically showing a conventional method of manufacturing a diamond heat sink.

15 DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to Figs. 1(a) and 2(a) to 2(c), a first process of manufacturing diamond heat sinks is now described. First, a polycrystalline diamond 201 is prepared by chemical vapor deposition (step 101). Referring to Fig. 2(a), the polycrystalline diamond 201 is metallized, so that a metallized film is formed over 20 the entire surface of the polycrystalline diamond 201 (step 102). Referring to Fig. 2(b), the metallized polycrystalline diamond 201 is grooved with a laser, so that grooves 202 are vertically and horizontally formed on the upper surface of the polycrystalline diamond 201 (step 103). Referring to Fig. 2(c), the grooved polycrystalline diamond 201 is mechanically divided along the grooves 202, thereby forming diamond heat sinks 203 (step 104).

25 Referring again to Figs. 1(a) and 2(a) to 2(c), a second process of manufacturing diamond heat sinks is now described. Referring to Fig. 2(a), a polycrystalline diamond 201 is prepared by chemical vapor deposition (step 101). Referring to Fig. 2(b), this polycrystalline diamond 201 is grooved with a laser, so that grooves 202 are vertically and horizontally formed on the upper surface of the polycrystalline diamond 201 (step 112). The grooved polycrystalline diamond 201 is metallized, so that a metallized film is formed over 30 the entire surface of the polycrystalline diamond 201 (step 113). Referring to Fig. 2(c), the metallized polycrystalline diamond 201 is mechanically divided along the grooves 202, thereby forming diamond heat sinks 203 (step 104).

The structure of a diamond heat sink manufactured by the aforementioned method is now described.

Referring to Figs. 1(b) and 3, a diamond heat sink 10 includes a polycrystalline diamond 11 and 35 metallized films 12. The polycrystalline diamond 11 has a first layer 11a which is grooved with a laser and a mechanically divided second layer 11b. The first layer 11a is heated when the same is worked with the laser, whereby graphite is generated around its outer peripheral surface to adhere to the same. On the other hand, the second layer 11b is mainly composed of columnar crystals, due to the preparation by vapor deposition. Upon mechanical division, therefore, the polycrystalline diamond 11 is parted by both cleavage 40 along (111) planes of the crystals and rupture along grain boundaries. Thus, the outer peripheral surface of the second layer 11b is larger in surface roughness than that of the first layer 11a. In more concrete terms, the first and second layers 11a and 11b are about 5 μm and 10 μm in surface roughness respectively.

The second layer 11a has a thickness L_1 in a range of at least 0.03 mm and not more than 0.3 mm. On the other hand, the portion grooved with the laser has a thickness L_2 in a range of at least 5 μm and not 45 more than 20 μm .

An edge of the second layer 11b may be chipped by the mechanical division, to cause a defective portion 15. Such a defective portion 15 is suppressed to be not more than 50 μm in size.

Each of the metallized films 12 is preferably formed by a plurality of films including a first film 12a and a second film 12b.

50 The first film 12a is made of at least one element selected from Ti, Cr, W and Ni as an element film, an alloy film or a multilayer film of the same.

The second film 12b is made of at least one element selected from Pt, Pd, Ni, Mo, Au, Ag, Cu, Sn, In, Ge and Pb as an element film, an alloy film or a multilayer film of the same.

55 Fig. 3 is a side elevational view showing a polycrystalline diamond which is grooved with a laser and thereafter mechanically divided. This polycrystalline diamond is not metallized on the side faces.

Relations between laser beam machining conditions employed for manufacturing the diamond heat sink and depths of the worked grooves are now described.

Referring to Fig. 4, the depths of worked grooves are increased as the scanning speed is reduced or the number of scanning times is increased under the same laser outputs. Also in a polycrystalline diamond which is synthesized by a hot filament method and a monocrystalline diamond which is synthesized by high pressure synthesis, relations between laser beam machining conditions and depths of worked grooves are similar to those shown in Fig. 4.

Example of the inventive method of manufacturing a diamond heat sink is now described. First, a polycrystalline diamond was synthesized by microwave plasma CVD, in dimensions of 25.4 mm by 25.4 mm with a thickness of 0.3 mm. This polycrystalline diamond was finished into a thickness of 0.25 mm by grinding. The surfaces of the as-ground polycrystalline diamond were metallized by vapor-depositing Ti, Pt and Au in this order, in thicknesses of 600 Å, 800 Å and 1000 Å respectively. One of the metallized surfaces of the polycrystalline diamond was grooved with a YAG laser in the form of a lattice with pitches of 0.77 mm. The polycrystalline diamond was worked at an output of 3 W, a Q-switching frequency of 3 KHz and a scanning speed of 1 mm/s by a single scanning time. The as-formed grooves were 0.15 mm in depth.

Then, a wedge of stainless steel was driven into the grooves of the polycrystalline diamond, to pressurize the same. Due to such pressurization, the polycrystalline diamond was easily cut along the grooves.

In the aforementioned process, obtained were polycrystalline diamond heat sinks, each of which was 0.75 mm by 0.75 mm with a thickness of 0.25 mm, having upper and bottom surfaces covered with Ti-Pt-Au metallized films. In the process of manufacturing such polycrystalline diamond heat sinks, the maximum size of defective portions which were caused in edges of the heat sinks was 30 µm, while the working yield was 100 %. Electric resistance across the upper and lower metallized films of each diamond heat sink was $5 \times 10^8 \Omega$. The polycrystalline diamond employed in this Example had specific resistance of $5 \times 10^9 \Omega \cdot \text{cm}$, and thermal conductivity of 15 W/cm²K at a temperature of 25 °C.

The structure of a diamond heat sink completed by the aforementioned method is now described.

Referring to Fig. 5, a diamond heat sink 410 is formed by a polycrystalline diamond 411 and metallized films 412 which are formed on upper and bottom surfaces of the polycrystalline diamond 411. Each of the metallized films 412 is made of Ti, Pt and Au in this order from a side which is in contact with the polycrystalline diamond 411. Thus structured is a diamond heat sink according to Example of the present invention.

On the other hand, a material of 0.25 mm in thickness was prepared from a monocrystalline diamond which was synthesized by high pressure synthesis. This monocrystalline diamond was metallized and worked with a laser under the same conditions as the above. As the result, grooves of 0.15 mm in depth were formed similarly to the case of the polycrystalline diamond. However, this monocrystalline diamond was easy to crack with defective portions of at least 100 µm and hard to cut, with an inferior working yield of 10 %.

Another Example of the inventive method of manufacturing a diamond heat sink is now described.

A polycrystalline diamond was synthesized by a hot filament method, in dimensions of 50.8 mm by 50.8 mm with a thickness of 0.8 mm. This polycrystalline diamond was finished into a thickness of 0.635 mm by grinding. Upper and lower surfaces of the as-ground polycrystalline diamond were grooved with a YAG laser. Thus, grooves were formed in the upper and bottom surfaces of the polycrystalline diamond with pitches of 20.1 mm, at a laser output of 2.5 W, a Q-switching frequency of 3 KHz and a working speed of 0.5 mm/s by 6 scanning times. The upper and bottom grooves were displaced by 10 µm from each other, with depths of 0.25 mm from the upper and bottom surfaces respectively.

The upper and bottom surfaces of the grooved polycrystalline diamond were metallized with Ti, Mo, Ni and Au in this order by sputtering, in thicknesses of 600 Å, 800 Å, 1000 Å and 5000 Å respectively. Then, either one of the metallized upper and bottom surfaces of the polycrystalline diamond was covered with a metallized film of an Au/Sn eutectic alloy by physical vapor deposition. The thickness of the metallized film of the Au/Sn eutectic alloy was 3 µm.

A lattice-shaped metal jig, which was worked in response to the shapes of the grooves, was introduced into the grooves of the metallized polycrystalline diamond, to pressurize the same. Due to such pressurization, the polycrystalline diamond was easily cut along the grooves, to obtain polycrystalline diamond heat sinks.

Electric resistance across the upper and bottom metallized films of each diamond heat sink was $1 \times 10^7 \Omega$. The maximum size of defective portions which were caused in edges of the diamond heat sinks was 20 µm. The polycrystalline diamond employed in this Example had electric resistivity resistance of $2 \times 10^9 \Omega \cdot \text{cm}$ and thermal conductivity of 10 W/cm²K at a temperature of 100 °C.

The structure of a diamond heat sink completed in the aforementioned manufacturing method is now described.

Referring to Fig. 6, a diamond heat sink 420 is formed by a polycrystalline diamond 421, metallized films 422 and a metallized film 423 of an Au/Sn eutectic alloy. The metallized films 422 are formed on upper and bottom surfaces of the polycrystalline diamond 421. Each of the metallized films 422 is formed by four layers of Ti, Mo, Ni and Au in this order from a side which is in contact with the polycrystalline diamond 421. Either one of the upper and bottom surfaces, which are provided with the metallized films 422, of the polycrystalline diamond 421 is covered with the metallized film 423 of an Au/Sn eutectic alloy. The diamond heat sink 420 according to the other Example of the present invention is formed in the aforementioned manner.

As to a monocrystalline diamond which is synthesized by high pressure synthesis, it is impossible to synthesize a material in dimensions of 20 mm by 20 mm with a thickness of 0.635 mm through the present technology. When upper and bottom surfaces of a material of 4 mm by 4 mm having a thickness of 0.635 mm were worked with a laser to be subjected to a cutting test, it was impossible to cut the same due to a crack caused from cut portions.

Although the present invention has been described and illustrated in detail, it is clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of the present invention being limited only by the terms of the appended claims.

20 Claims

1. A method of manufacturing a diamond heat sink containing diamond being synthesized by chemical vapor deposition and having a pair of opposing main surfaces being electrically insulated from each other, said method comprising:
25 a step (101) of preparing said diamond (201) in the form of a polycrystalline diamond;
 a step (103, 112) of forming grooves (202) in surfaces of said polycrystalline diamond; and
 a step (104) of mechanically dividing said polycrystalline diamond along said grooves.
2. A method of manufacturing a diamond heat sink in accordance with claim 1, wherein said step of forming grooves (202) is carried out with a YAG laser.
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3. A diamond heat sink (10) containing polycrystalline diamond (11) being synthesized by chemical vapor deposition and having a pair of opposing main surfaces being electrically insulated from each other, said diamond heat sink comprising:
35 a first layer (11a) and a second layer (11b) provided between said pair of main surfaces, said first layer containing graphite adhering to its outer peripheral surface,
 the outer peripheral surface of said second layer being larger in surface roughness than that of said first layer.
4. A diamond heat sink (10) in accordance with claim 3, wherein a defective portion caused on an edge of said second layer is not more than 50 μm in size.
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5. A diamond heat sink (10) in accordance with claim 3, wherein electric resistance along the direction of thickness of said second layer (11b) is at least $1 \times 10^6 \Omega$.
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6. A diamond heat sink (10) in accordance with claim 3, wherein electric resistance across said pair of main surfaces is at least $1 \times 10^6 \Omega$.
7. A diamond heat sink (10) in accordance with claim 3, wherein said second layer (11b) has a thickness of at least 0.03 mm and not more than 0.3 mm.
50
8. A diamond heat sink (10) in accordance with claim 3, wherein said polycrystalline diamond (11) has electrical resistivity of at least $10^9 \Omega \cdot \text{cm}$.
9. A diamond heat sink (10) in accordance with claim 3, wherein said polycrystalline diamond (11) has thermal conductivity of at least 5 W/cm \cdot K and not more than 20 W/cm \cdot K at room temperature.
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10. A diamond heat sink (10) in accordance with claim 3, further including a metallized film (12) being formed on at least all or a portion of either one of said pair of main surfaces.
11. A diamond heat sink (10) in accordance with claim 10, wherein said metallized film (12) includes a first film (12a) being formed on at least either one of said pair of main surfaces and a second film (12b) being formed on the surface of said first film.
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12. A diamond heat sink (10) in accordance with claim 11, wherein said first film (12a) included in said metallized film (12) is made of at least one element selected from a group of Ti, Cr, W and Ni, and said second film (12b) is made of at least one element selected from a group of Pt, Pd, Ni, Mo, Au, Ag, Cu,
10 Sn, In, Ge, Sn and Pb.

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FIG. 1

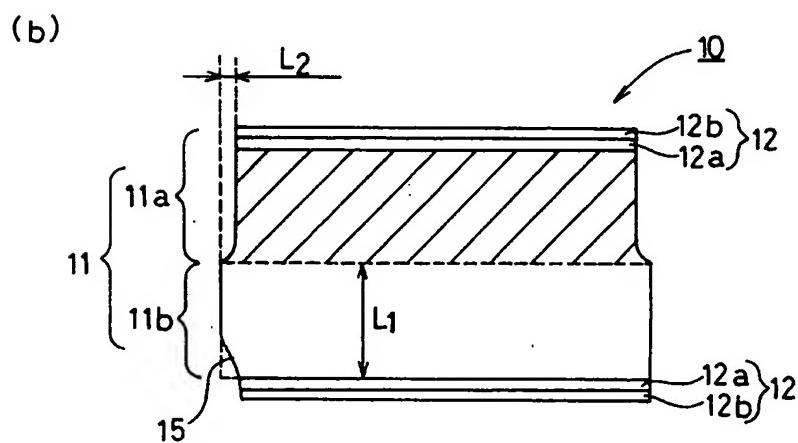
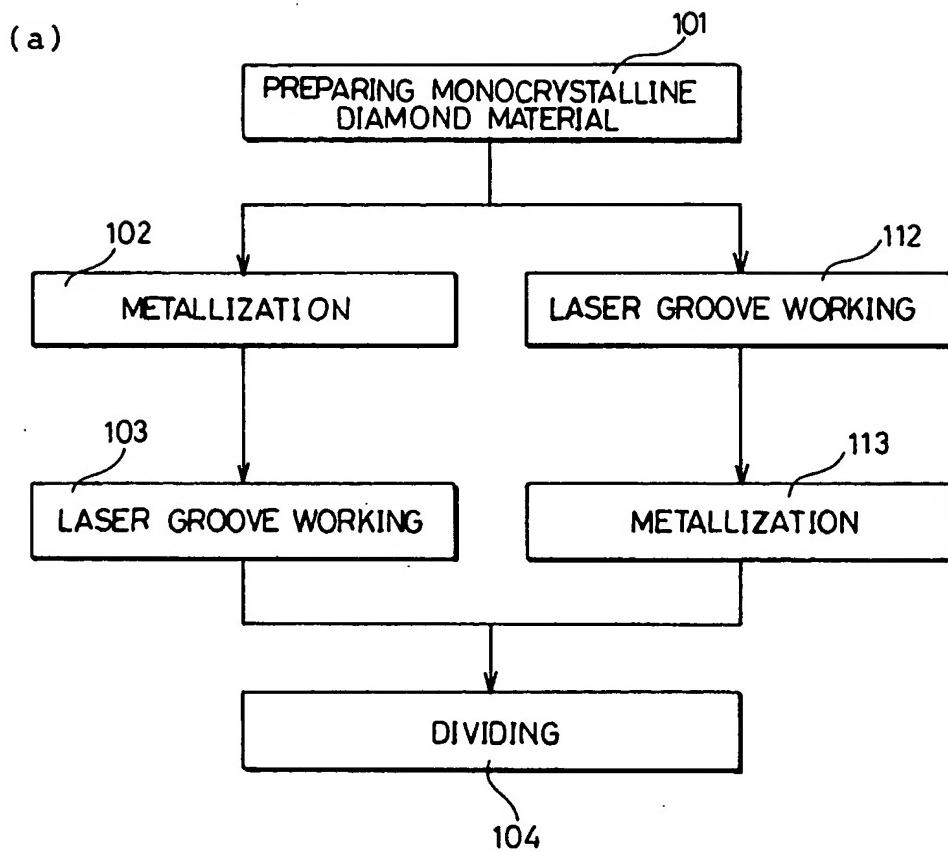
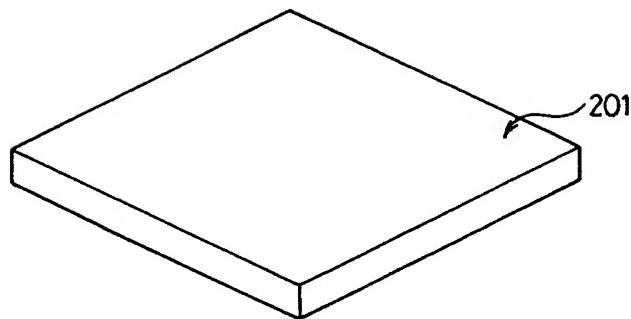
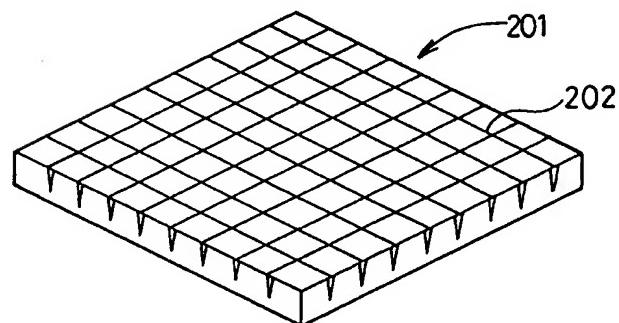


FIG. 2

(a)



(b)



(c)

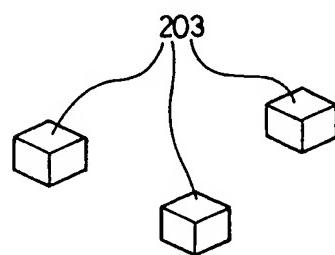


FIG. 3

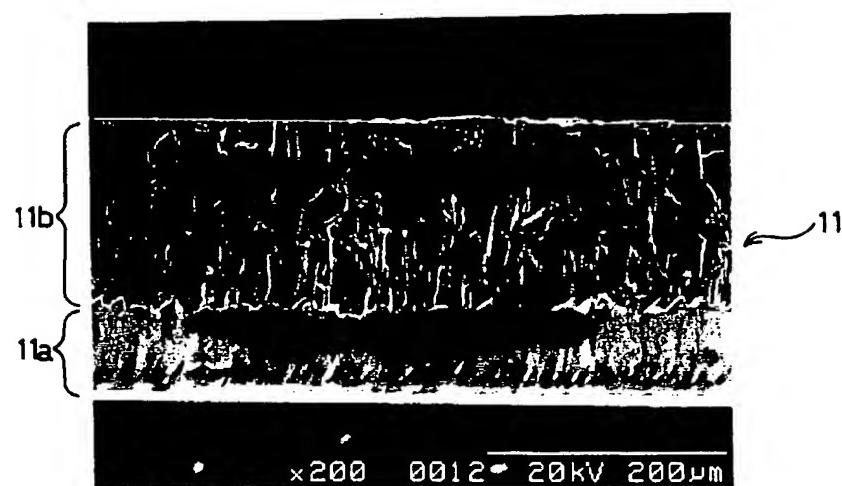


FIG. 4

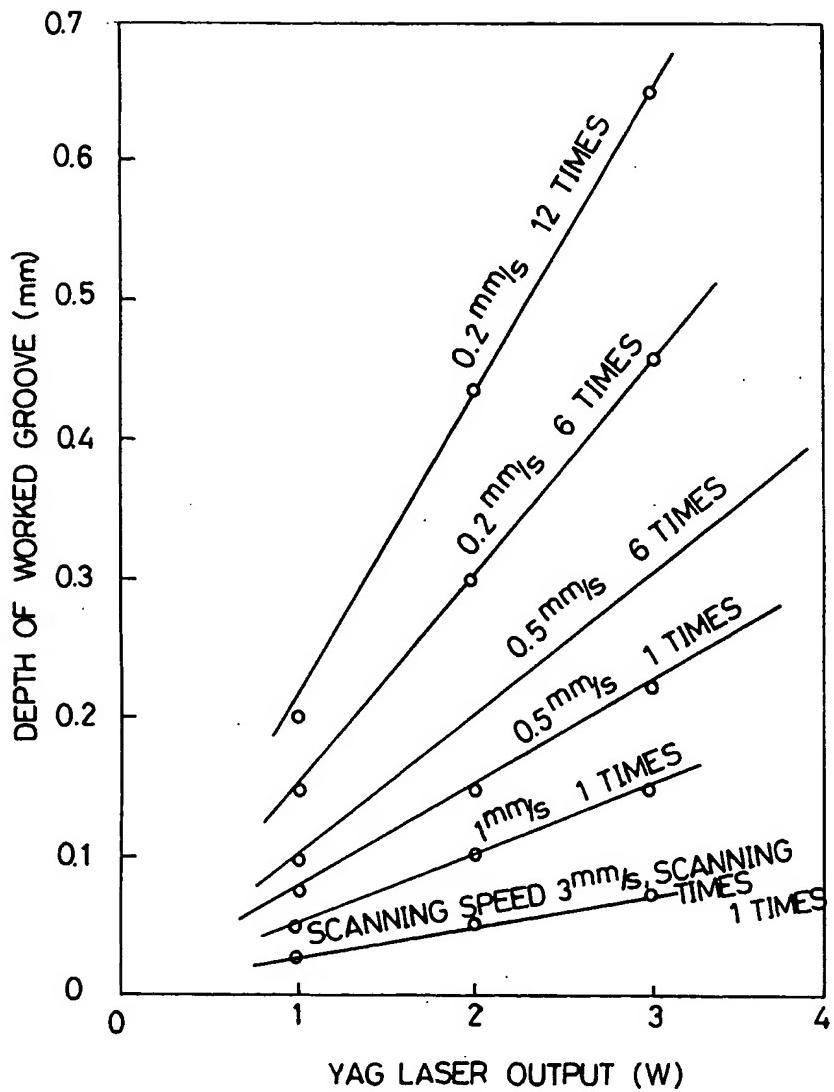


FIG.5

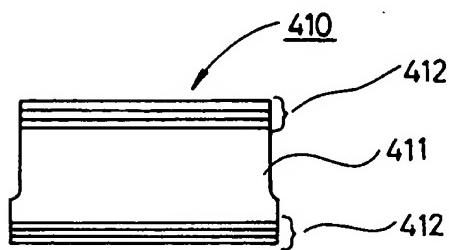


FIG. 6

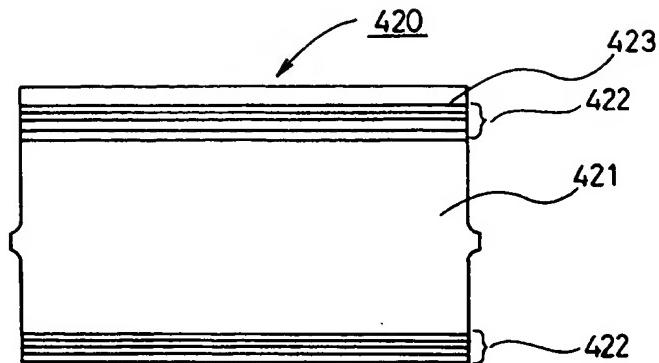
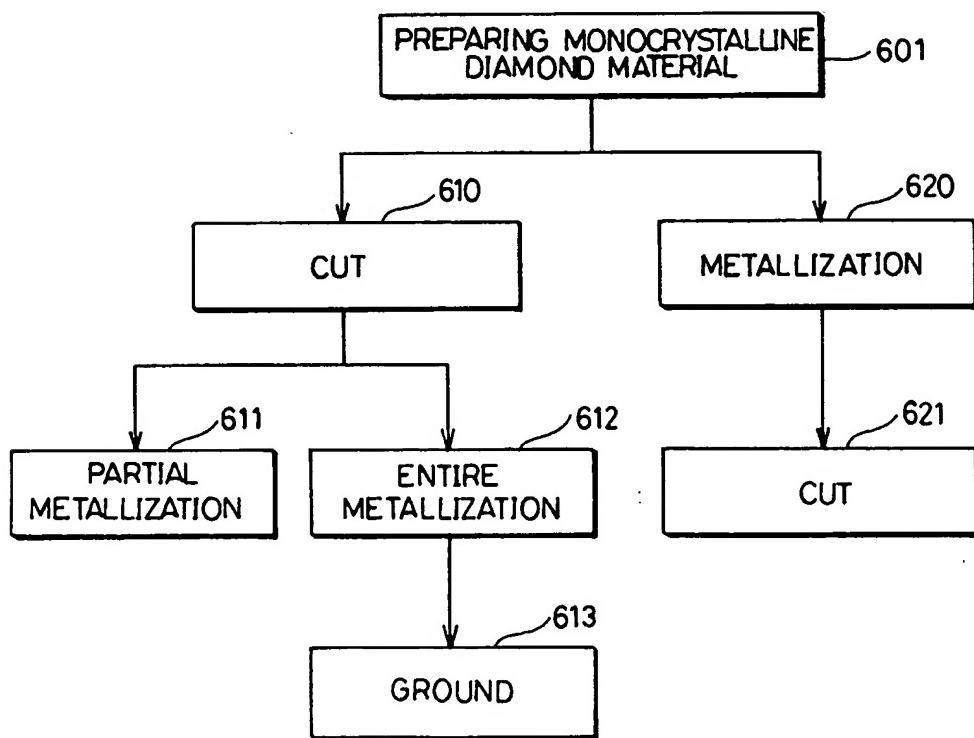


FIG. 7





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Application Number

EP 92 11 7932

| DOCUMENTS CONSIDERED TO BE RELEVANT | | | CLASSIFICATION OF THE APPLICATION (Int. Cl.5) | | | | | | |
|--|--|---|---|-----------------|----------------------------------|----------|-----------|------------------|-----------------|
| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | | | | | | | |
| Y | US-A-4 981 818 (GENERAL ELECTRIC) * claim 1 * --- | 1 | H01L23/373 H01L21/48 | | | | | | |
| Y | PATENT ABSTRACTS OF JAPAN vol. 6, no. 136 (E-120)23 July 1982 & JP-A-57 060 861 (NEC) 13 April 1982 * abstract * | 1 | | | | | | | |
| A | --- | 2 | | | | | | | |
| A | EP-A-0 142 282 (PLESSEY) * page 3, line 5 - line 9; claims 1,3,4 * --- | 1,12 | | | | | | | |
| A | PATENT ABSTRACTS OF JAPAN vol. 9, no. 284 (E-357)12 November 1985 & JP-A-60 127 750 (SUMITOMO) 8 July 1985 * abstract * | 3,7,9, 10,12 | | | | | | | |
| | | | TECHNICAL FIELDS SEARCHED (Int. Cl.5) | | | | | | |
| | | | H01L | | | | | | |
| <p>The present search report has been drawn up for all claims</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">Place of search</td> <td style="width: 33%;">Date of completion of the search</td> <td style="width: 34%;">Examiner</td> </tr> <tr> <td>THE HAGUE</td> <td>07 DECEMBER 1992</td> <td>DE RAEVE R.A.L.</td> </tr> </table> | | | | Place of search | Date of completion of the search | Examiner | THE HAGUE | 07 DECEMBER 1992 | DE RAEVE R.A.L. |
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| THE HAGUE | 07 DECEMBER 1992 | DE RAEVE R.A.L. | | | | | | | |
| CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document | | T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document | | | | | | | |

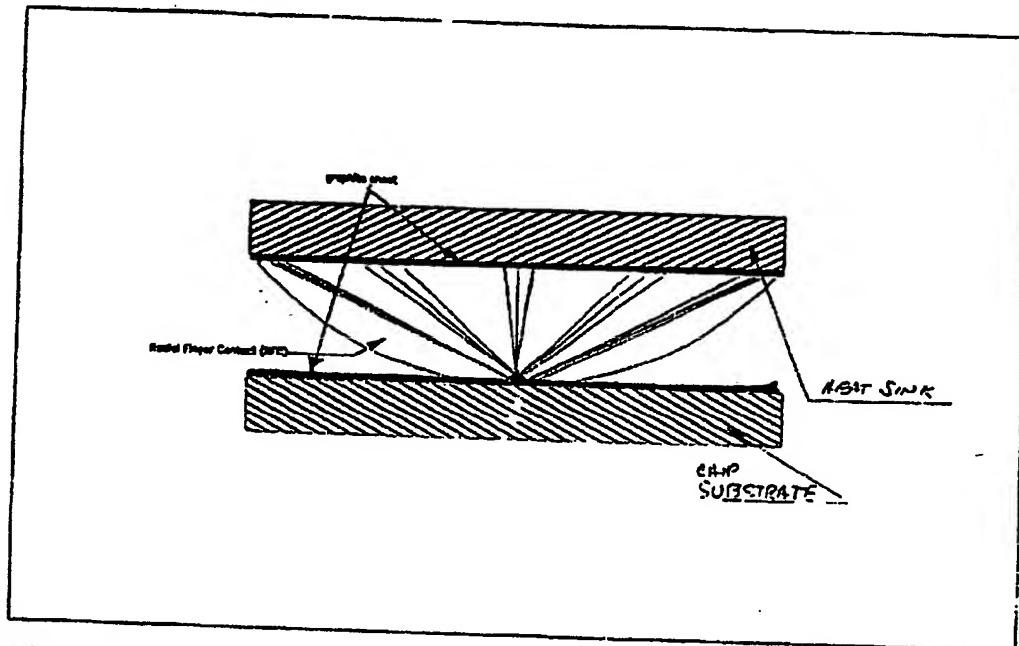
High Conduction Thermal Interface Material

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**Figure 1.**

This publication is to disclose the experimentation for a reduction of thermal interface resistance without the use of thermally conductive oils or grease.

The use of direct chip attach and increased chip power requires new and novel techniques of cooling at the chip level. When using large heat sinks to cool multi-chip arrays, a number of problems need to be addressed;

1. Surface irregularities of the interface area will increase thermal contact resistance substantially.
2. Thermal expansion coefficients of the materials in the chip, printed circuit card and the heat sink vary.
3. Tolerances of the parts used must be practical in the manufacturing process.
4. Thermal performance of the assembly must not deteriorate over time thereby effecting reliability.

Flexible devices are being introduced to overcome the above mentioned problems associated with the chips to heat sink interface. A common problem of these techniques is the high thermal interface resistance between the chip, flexible device and the cold plate. Thermal oils and grease

High Conduction Thermal Interface Material -- Continued

are methods of reducing this interface resistance. However thermal grease and oils are not desirable from a manufacturing stand base migration to other parts of the card such as connectors and there is a deterioration of the interface due to drying out and thermal cycling over time.

The purpose of this experiment was to compare the thermal resistance of a flexible graphite material of expanded graphite particles with that of thermal grease between the chip and the heat transfer device. This material eliminates the problems associated with the use of thermal grease and oils.

A test card assembly, 99 mm x 140 mm, with simulated chip devices installed was used for evaluation. Chip temperatures were measured and power levels varied as shown in Fig. 2. A "Radial Finger Contact Device" (RFC) was used as the flexible chip to heat sink interface device. (Fig. 1.)

Various interface configurations were tested and temperature rise recorded as shown in Fig. 2.

TEMPERATURE RISE IN C°

| CHIP | POWER | RFC ONLY | RFC WITH THERMAL GREASE INTERFACE | RFC WITH GRAPHITE SHT INTERFACE |
|------|-------|----------|-----------------------------------|---------------------------------|
| 1 | 3.3 | 29.2 | 15.2 | 19.5 |
| 2 | 1.9 | 17.2 | 12.0 | 14.2 |
| 3 | 1.9 | 17.2 | 12.0 | 14.2 |
| 4 | 1.9 | 17.2 | 12.0 | 14.2 |
| 5 | 2.4 | 24.3 | 14.7 | 18.9 |
| 6 | 2.4 | 21.7 | 14.9 | 16.5 |
| AVG | 2.1 | 21.0 | 13.6 | 16.3 |

Figure 2.

Results shown indicate the thermal performance of the graphite material approaching that of thermal grease. Using the average of the six chips, the difference in thermal resistance can be calculated from the formula in Fig. 3.

High Conduction Thermal Interface Material — Continued

$$\Delta T = P \times R.$$

where

P = power

R = overall resistance

$$\Delta R = R_{\text{grease}} - R_{\text{graph}} = \left(\frac{\Delta T}{P} \right)_{\text{grease}} - \left(\frac{\Delta T}{P} \right)_{\text{graph}} = \frac{\Delta T}{P} = \frac{2.7}{2.1} = 1.28^\circ\text{C/W}$$

Figure 3.

Thus, the increase in thermal interface resistance by using the graphite material rather than thermal grease is only 1.28 C/W. There is a significant improvement over the RFC interface only.

The graphite material used for this test was manufactured by Union Carbide Incorporated under the name "GRAFOIL". GRAFOIL and other similar materials have been used routinely for a thermal interface between high power transistors and heat sinks. Use as described in this report seems to be a novel application. The material is made from voluminously expanded graphite particles which have been compressed into a sheet approximately .005 inch thick. The sheet may be embossed or plated with metallic particles such as aluminum, tantalum carbide or the like to alter bonding or heat transfer characteristics. GRAFOIL is electrically conductive unless coated. Diamond powder and other types of dielectrics have been used to coat GRAFOIL, {*} type materials.

Reference

[*]U.S. Patent 3,404,061